INVESTIGATIONS ON LIGHT AND HEAT MADE AND PUBLISHED WHOLLY OR IN PART WITH APPROPRIATION FROM THE RUMFORD FUND.

II.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XXI.—COMPARISON OF ALCOHOL THERMOMETERS BAUDIN 8208 AND 8209 WITH THE AIR THERMOMETER AT LOW TEMPERATURES.

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THE results given in this paper were reached in a somewhat careful study of the alcohol thermometer made in the Physical Laboratory of the Institute of Technology during 1881–82. The study, though by no means exhaustive, developed some points of value which are here given. The comparison with the air thermometer agrees substantially with that published by Jolly.*

The alcohol thermometers used were two centigrade tubes, made by Baudin, Paris, in 1880. They were precisely similar, and of the following dimensions: total length, 50 cm.; length of bulb, 4.5 cm.; length of 1° C., 0.28 cm.; divided to 0°.1 C.; range from +35° to —90° C.

The air thermometer was of the Jolly type, but the mercurial columns were read by a cathetometer. Its bulb was of small size, diameter 3.48 cm., to insure a rapid equalization of the temperature within and without, and to allow the use of a small bath of liquid nitrous oxide.

The cathetometer was by Staudinger. Its scale was in millimeters with vernier reading directly to $\frac{1}{20}$ mm. and by estimation to 0.01 mm. The scale errors had been determined by Prof. William A. Rogers of Harvard University, and corrections were applied. The barometer, by James Green, was of the Fortin type, and read to 0.002 inch. The scale and instrument errors had been previously determined.

* Pogg. Ann. Jubelband (1874).

The temperatures, T, by the air thermometer, were computed as described in Professor Rowland's paper on the Mechanical Equivalent of Heat.* The numerical value of v was 0.80 cc.; of V, 20.21 cc. The themometer was first filled with air dried by calcium chloride and concentrated sulphuric acid. The coefficient of expansion of this air was then measured several times. Six independent measurements gave values of $a =$

0.003699	0.003699
3707	3702
3685	3702

Average = 0.003699

These results are sufficiently concordant in view of the small capacity of the bulb of the thermometer, but the average is nearly one per cent higher than the proper value, 0.003670. The cause of this deviation is unknown. It is possibly in part due to imperfect drying of the air. Its effect on the resulting temperature measurements will be small, however, since a and T are determined by the use of the same mass of air, and the moisture, if any were present, must have been in so small quantity as not sensibly to influence the results through condensation, etc. If the deviation be due to any undetected constant error, it will produce but little error in the temperatures obtained, since the air thermometer is used under essentially the same conditions for the determination of a and of T.

The vessel for holding the cold bath, or "freezing mixture," was composed of several concentric glass and metal vessels, the spaces between successive vessels being filled either with dry sawdust or with a freezing mixture, or with these alternating. The arrangement employed when the freezing mixture of salt and ice was used consisted of five concentric vessels. Between the outer and the second vessels was a space filled with sawdust. Between the second and third was a space of larger capacity than the former, which contained a mixture of salt and ice. Between the third and fourth vessels was another sawdust layer; and between the fourth and inner vessels, a second freezing mixture of salt and ice; while the inner vessel was filled with alcohol, in which the bulbs were immersed and which was thoroughly stirred. A suitable cover of several thicknesses of badly conducting material was provided for the whole. When the liquid nitrous oxide was used, the whole space between the third and a

* These Proceedings, June, 1879, vol. xv.

smaller interior glass vessel was packed with sawdust, the first outer bath of salt and ice being retained. Instead, however, of filling the innermost vessel with the liquid nitrous oxide alone, the space was first filled with fine copper turnings and filings. These occupied so much of the volume as considerably to reduce the amount of the liquid N_2O required, and at the same time by their good thermal conductivity tended to maintain a uniform temperature throughout the mass without stirring. The device was found very satisfactory in operation. The liquid N_2O was obtained by the rapid discharge of a cylinder somewhat highly charged with the gas. The cylinder was one of those in which this gas is commercially distributed for use as an anæsthetic, but was more highly charged than is usual.

In the comparison of the alcohol and air thermometers, the conditions were necessarily rather unfavorable for high precision, but the arrangements adopted are believed to have given mean results correct to 0°.5 C., or (probably) less at the lowest temperatures reached, as high a degree of precision as can be relied upon with the alcohol thermometer. The difficulty and expense of using a large bath of liquid nitrous oxide precluded the total immersion of the thermometer in the bath at low temperatures, and as it was thought desirable to work under the same conditions as to stem exposure at all temperatures, the same general arrangement was used throughout. The bulb and an inch or two of the capillary were therefore the only parts of the thermometers immersed, the remainder of the stem being surrounded by a thin glass tube of about an inch in diameter, filled with water, which, when properly stirred, rendered the temperature of the stem uniform, and measurable (by an auxiliary thermometer). The two alcohol thermometers passed side by side through the same stem bath, and had their bulbs nearly in contact with each other and with the air bulb in the cold bath.

The scale of the alcohol thermometers was supposed to be normal, i. e. of lines so spaced as to separate equal volumes of the capillary, and to give approximate degrees by direct reading. It was also supposed that the spacing of the degrees was determined by the use of ice, and by comparison with a standard mercurial thermometer at one or more temperatures, probably above 0° C., or by some equivalent process, so that one degree of the scale at or near 0° C. corresponds as closely as may be with 1° C. as ordinarily defined on the mercurial thermometer, or, more precisely, with the degree as measured with the Baudin standard mercurial thermometer. It was obviously of no special interest, therefore, to study further the temperature value of

one division of the scale, although through the failure to do so the investigation lacks completeness.

The correction for the temperature difference between the stem and bulb, i. e. the "stem exposure correction," was made through the use of the customary expression,

$$n\,(T-t)\,k,$$

where

$T =$ the temperature of the bulb, in these measurements given by the air thermometer.

$t =$ the temperature of the exposed stem,

$n =$ the length expressed in degrees of the exposed alcohol column,

$k =$ the coefficient of apparent expansion of the alcohol in the glass of the thermometer.

The value of k was measured in two ways: first, by an independent study with the alcohol bulbs in ice and the projecting stems at measured temperatures; secondly, from the results in the comparison with the air thermometer at about 0° C. These gave results in substantial agreement, but the second method was considered more reliable, and likely to aid in eliminating constant errors in the comparison since made under the same conditions, and its value of $k = 0.00091$ was adopted.

The readings of the thermometers in ice were taken at intervals, to follow the changes with age and usage, and the instruments were never raised to a temperature above that incidental to the manipulation. The zero point of 8209 rose from —0°.18 C., in October, 1880, to +0°.16 in April, 1882. The change in 8208 was probably about the same, but the data do not extend over the same time.

The following are the mean values obtained by averaging in suitable groups the eighty readings obtained in the comparison with the air thermometer.

Air Therm.	8208.	8209.	δ_8.	δ_9.	$\delta_9 - \delta_8$.
°	°	°	°	°	°
+ 0.72	+ 0.69	+ 0.69	—0.03	—0.03	0.00
— 2.06	— 2.00	— 2.00	+0.06	+0.06	0.00
— 6.86	— 6.68	— 6.63	0.18	0.23	0.05
—10.45	—10.08	—10.03	0.37	0.42	0.05
—16.37	—15.59	—15.47	0.78	0.90	0.12
—19.80	—18.80	—18.67	1.00	1.13	0.13
—87.94	—79.02	—78.46	8.92	9.48	0.56

The first column gives the temperatures by the air thermometer, the second column the corrected readings by Baudin 8208, the third the corrected readings for 8209, the fourth the deviation of 8208 from the air thermometer, the fifth the same for 8209, and the sixth the differences between the two Baudin thermometers. In the series of eighteen comparisons which give the means corresponding to —87°.94 the average deviation of the single numbers giving the mean in the fourth or fifth columns was 0°.16.

For the sake of comparison, the figures published by Jolly are here appended.

Air Therm.	Alcohol.	δ.
° — 6.32	° — 6.21	° 0.11
—11.02	—10.72	0.30
—15.25	—14.41	0.84
—19.29	—18.02	1.27
—79.44	—70.72	8.72